THE STUDY OF TERRESTRIAL SOLAR RADIATION IN AWKA USING MEASURED METEOROLOGICAL DATA

ABSTRACT

This work investigated the terrestrial solar radiation over Awka, South Eastern Nigeria using meteorological parameters of terrestrial temperature and relative humidity collected from 2013- 2014 respectively, using Davis weather station vantage pros2 (with Integrated Sensor Suite, ISS) positioned close to the ground surface. The data were logged at 30 minutes interval continuously for each day during the period. Hourly, daily and monthly averages of terrestrial solar radiation during dry and wet seasons were calculated from the data obtained. The result indicated that the terrestrial solar radiation during dry season is generally higher than during the wet season. The month of March has the highest value of terrestrial solar radiation of 410 Wm^{-2} , while the least terrestrial radiation of about 381 Wm^{-2} occurred in August. The result also showed that terrestrial solar radiation correlates positively with water vapour and more positively with temperature at 0.57 and 0.81 coefficients respectively. The results obtained from this work provide useful knowledge which is necessary to enhance the deployment of solar energy conversion systems.

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Keywords: Terrestrial solar radiation; temperature; humidity; Awka; solar energy conversion systems.

1. INTRODUCTION

Terrestrial solar radiation is a long-wave electromagnetic radiation in the form of heat energy emitted from the Earth surface and it atmosphere in the temperature range of 200 – 300 K. The flux density in the form of energy transported by this radiation is measured in Watt per metre square (W/m^2) over the wavelengths of between 4μm and 100μm in the electromagnetic spectrum. Terrestrial solar radiation depends on the temperature of the radiating body (earth's surface), surface emissivity, atmospheric temperature; water vapour profile and cloud cover [1]. This radiation involves processes of absorption, scattering and emissions from atmospheric gases, aerosols, clouds and the surface. The lowest layer of the atmosphere generally called the troposphere is closely affected by terrestrial solar radiation and since this site allows temperature decrease with increasing altitude, warm air near the Earth surface becomes less dense and rises replacing cold air at the upper troposphere. By so

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doing vertical movement of convective current is produced thereby creating cloud which ultimately rain from the moisture within the troposphere that form part of the weather which we experience.

However, terrestrial solar radiation is critical to Earth's radiation budget. It forms the total radiation going to the space emitted by the Earth's atmosphere [1]. Radiation balance is quite achieved since the outgoing long wave radiation equals the short wave incoming radiation received at high energy from the sun. Consequently, the Earth's average temperature is affected by clouds and greenhouse gases which block some of these radiations from escaping into the outer space thereby contributing to global warming which heats the Earth's atmosphere [2]. If the absorptivity of the gas is high and the gas is present in a high enough concentration, the absorption bandwidth becomes saturated. In this case, there is enough gas present to completely absorb the radiated energy in the absorption bandwidth before the upper atmosphere is reached, and adding a higher concentration of this gas will have no additional effect on the energy budget of the atmosphere**.**

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Moreover, accurate knowledge of terrestrial solar radiation is fundamental to cooling mechanism of Earth atmosphere system. Knowledge of its dependence on surface and atmospheric parameters is therefore relevant for quantitative understanding of climate and of climatic change [2]. Also, its knowledge is important to solar engineers and meteorologists to enhance solar energy conversion systems validate remote sensing estimate of solar energy flux and Earth's radiation budget.

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Hence, it is the intent of this research to investigate and characterize the terrestrial solar radiation variations derived from meteorological parameters over the two- year period (2013 and 2014) in Awka, the capital city of Anambra State.

2. CALCULATIONS OF TERRESTRIAL SOLAR RADIATION

Stefan Boltzmann formulated a law that related to the energy flux density which is proportional to the fourth power of absolute temperature. Because of that, emission of radiation from Earthly bodies changes considerably, even in the limited temperature range characteristics of a single day or season. This can be expressed mathematically as [3]:

$$E = \varepsilon\sigma T^4 \qquad (1)$$

Where E= terrestrial solar radiation, ε = emissivity of the surface, σ = Stefan Boltzmann's constant which is 5.67×10^{-8} $Wm^{-2}K^{-1}$ and T is the temperature measured in Kelvin.

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Emissivity can be calculated in terms of water vapour using the expression [4]:

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$$\varepsilon = 0.605 + 0.048e^{0.5} \qquad (2)$$

$$E = (0.605 + 0.048e^{0.5})\sigma T^4 \qquad (3)$$

Where e = water vapour pressure (hPa).

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The water vapour e is usually calculated from the relative humidity and saturated water vapour using the expression [5]:

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$$e = \frac{He_s}{100} \qquad (4)$$

$$e_s = 6.1121 exp\,(\frac{17.502t}{t+240.97}) \qquad (5)$$

$$e = \frac{H\times6.1121\ \exp\,(\frac{17.502t}{t+240.97})}{100} \qquad (6)$$

In general, changes in temperature (T) and water vapour pressure (e) cause change in the terrestrial solar radiation (E). The relative importance of these parameters (T, e) could also be observed from the differential of Eq. (2):

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$$\delta E = (\ 4.605\sigma T^3 + 4.048\sigma e^{0.5}T^3)\delta T + 0.024e^{-0.5}T^4\delta e \qquad (7)$$

Comment [K14]: This is not mathematically correct; it is not a derivation of eq.3

For typical atmospheric conditions, temperature T= 290K and e = 13.7hpa. Equation 7 reduces to:

$$\delta E = 27.087\delta T + 45.861 \times 10^6\delta e \qquad (8)$$

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It can be seen from eqn (8) that for a given change in terrestrial solar radiation the contribution of e is enormous compared to T. This is primarily due to the fact that water vapour has electric dipole moment that it absorbs radiation more strongly in the long wave spectrum occupied by the outgoing radiation. Radiation emitted from the Earth's surface are absorbed and remitted in the atmosphere. Again, water vapour pressure has amplifying effects that increase in temperature cause evaporation of water from the Earth surface which enters the atmosphere as water vapour, absorb and emit radiation through the continuous

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feedback loop of water vapour that resulted in the overall increase in terrestrial solar radiation.

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3. AREA OF STUDY AND DATA

The study of terrestrial solar radiation was carried out in Awka at Nnamdi Azikiwe University, Anambra State. It is situated at about 17 km by road away from the city of Awka, with coordinates (6°12′25″N 7°04′04″E). The area has two topographic features which are two ridges lying both in a North- South direction. Awka lies in a tropical rainforest zone of Nigeria and experienced two distinct seasons that are characterized by winds from the Atlantic Oceans and Sahara desert for wet and dry seasons respectively. The wet season falls between the months of April and October and characterized by heavy rainfall while the dry season on the other hand, covers other months (Novmber to March) and characterized by scanty or no rainfall filled with dry dust-laden atmosphere. The temperature in Awka is generally high of about 28- 34 degree Celsius between January and April.

Comment [K22]: November

The Devis 6162 wireless Vantage Pro2 weather station is an instrument used for this measurement. It is equipped with the Integrated Sensor Suite (ISS), a solar panal and the wireless console through which stored data are downloaded from the computer. The fixed measuring method was employed with the ISS close to the ground for the continuous measurement of terrestrial temperatures and relative humidity. 24- Hour measurement was carried out continuously each day beginning from 00 hours local time (LT) and logs at 30 minutes intervals. With the help of data logger attached to the console, the data were transmitted by wireless radio connection which was then copied to computer for analysis. The measured values of meteorological parameters (temperature and relative humidity) for two-year period of 2013 and 2014 were used for this work for the observed readings at all local times. Further analysis was carried out by averaging the data collected for each measurement period to give twenty four hours data for the diurnal variation over each month. Finally, the average data collected in 24 hours for each day was calculated. Each data was further averaged to give a data point for each month for the seasonal variation.

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4. RESULTS AND DISCUSSION

From the calculated values of the water vapour pressure. Terrestrial solar radiations were then determined. The values were observed to be generally high during the dry season (November

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– March). The high values are due to high temperatures occasioned by low humidity in the atmosphere that cause dryness and dust- laden north- easterly winds (*Harmattan)* to set in. The results obtained for the average of every representative dry and wet season months are presented in Figs. 1 and 2.

Fig. 1 shows mean diurnal variations of terrestrial solar radiation of a typical dry season month, January which drops from 00:00hr midnight to 02:00hr of that night. The undulation continues to a minimum value of about 357 Wm^{-2} by 9:00hr on that day. There is a rise in the value of E from that time to a value by 14:00hr on that day. Between 14:00hr and 21:00hr radiation values are fairly constant. It then rises to maximum value of 412 Wm^{-2} by 22:00hr. The drop in values of E from 00:00hr midnight to a minimum value in the day time is attributed to low values of T, e and e_s which combined together.

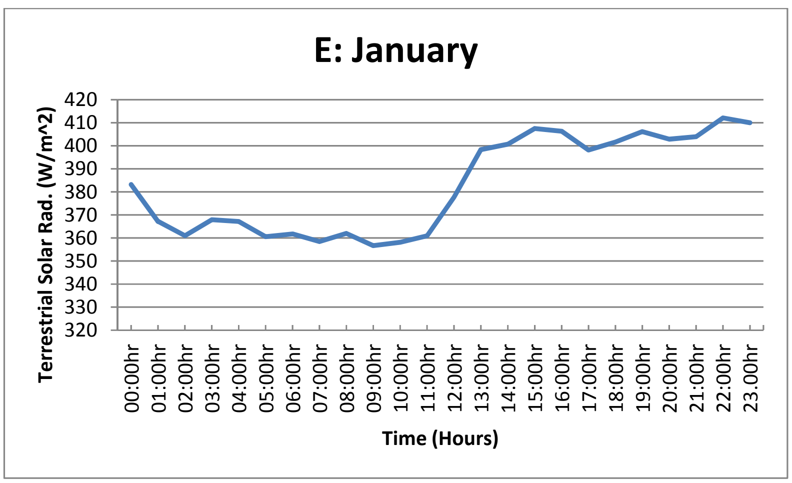

Fig.1: Mean diurnal variation of Terrestrial Radiation in January

The plot of terrestrial solar radiation profile of hourly variations has radiation range of 373 Wm^{-2} to 408 Wm^{-2}, Fig.2. The values are more or less stable throughout the night and day at lower radiation values than a typical dry season month, January. The month of July in Awka is a typical rainy season period associated with moisture-laden south westerly winds which increasingly saturates the air. This attributes to fairly higher stable values of RH, e and e_s which combined together.

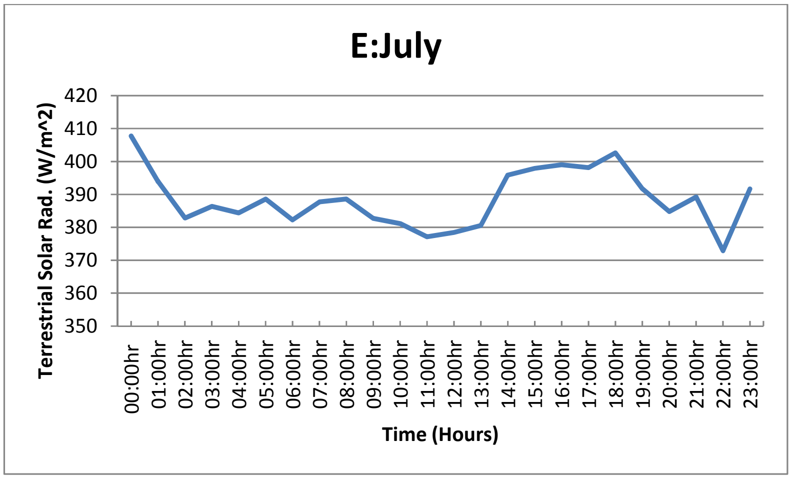

Fig. 2: Mean diurnal variation of Terrestrial Radiation in July

Fig.3 shows mean daily terrestrial solar radiation for both dry and rainy season months. The dry season months are November, December, January, February and March while the rainy season months are April, May, June, July, August, September and October. The dry season months have higher terrestrial radiation values from 16^{th} day of about 403 Wm^{-2} to the 28^{th} day of about 400 Wm^{-2}. The rainy season months have lower terrestrial radiation values in the ranges of between 395 Wm^{-2} to 220 Wm^{-2}. This is due to increased surface temperature which raises rate of emission of radiation during the dry season than rainy season. The entire plot in fig.3 shows that wet season months have lower terrestrial solar radiation values and less variability while the dry season months have higher terrestrial solar radiation values and higher variability.

From the Fig.4, it is observed that terrestrial radiation has the lowest value in August with a value of 381 Wm^{-2}. This attributed to low surface temperature and low radiation from the terrestrial surface. There is a gradual steady increase through the month of November when the surface temperature is high until it gets to the peak value. The mean maximum terrestrial solar radiation is 410 Wm^{-2} which occurs in the month of March. Plot of Fig.4 shows that the highest terrestrial solar radiation values occur in dry season months (November to March) while the least terrestrial radiation values occur in wet season months (April to October). The higher terrestrial radiation in dry season is as a result of increased terrestrial temperature

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which reduces the moisture content of the surface.

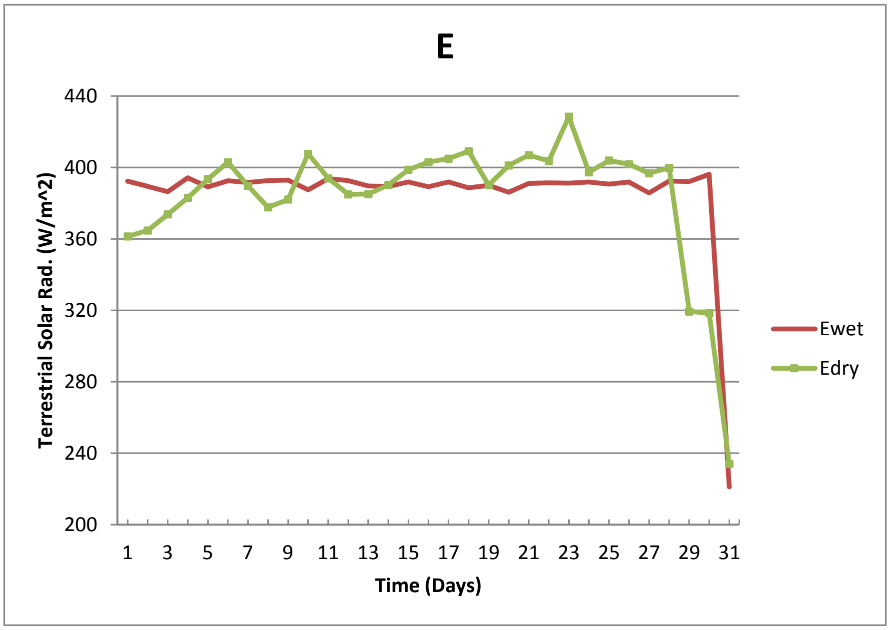

Fig.3: Mean Daily Variations of Terrestrial Solar Radiation for Dry and Rainy Season Months

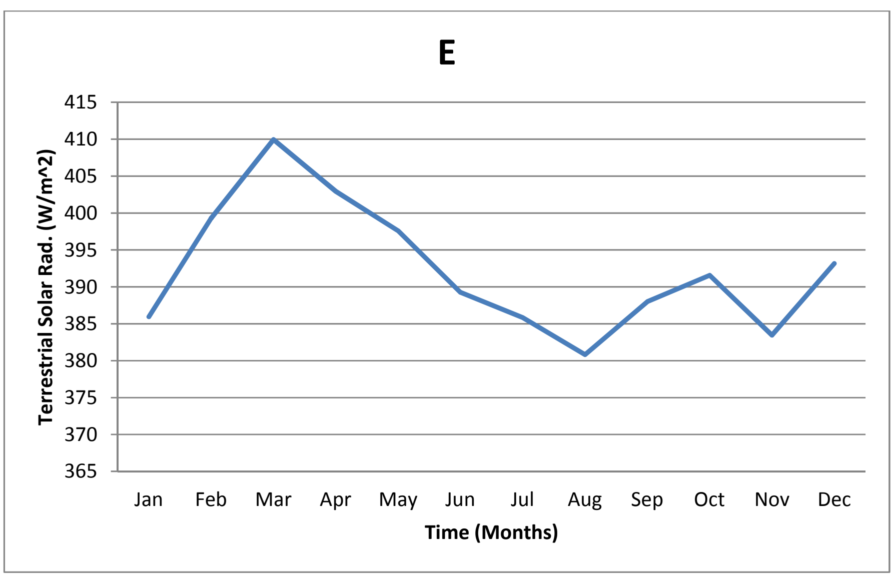

Fig.4 Mean Monthly Variation of Terrestrial Solar Radiation in Awka

5. CONCLUSIONS

The analysis of this work has shown that the terrestrial solar radiation over Awka showed a seasonal variation with higher values in the dry season and lower values in the wet season. E values range from 381 Wm^{-2} to 410 Wm^{-2} in dry season period and 381 Wm^{-2} to 403 Wm^{-2} in wet season period. The dry season variability of E is more than E variability in the wet season terrestrial solar radiation which has small variability. The average value of terrestrial solar radiation over Awka for the 2- year period of 2013- 2014 is 392 Wm^{-2}. Terrestrial solar radiation correlates positively with water vapour and more positively with temperature at 0.57 and 0.81 coefficients respectively.

Comment [K26]: vapor

REFERENCES

1. Susskind,J., Molnar,G., and Iredell,L., (2011). "Contribution to climate Research using the Airs science team version -5 products" 14(5):12-17.

2. Allan, R.P., Shine, K.P., Slingo, A., and Pamment, J.A., (1999).The dependence of clear –sky outgoing long-wave radiation on surface temperature and Relative humidity, 125(5): 2103-2126.

3. Duarta, H.F., Dias, N.L. and Maggiotto, S.R., (2006). Assessing daytime Downward longwave radiation estimates for clear and cloudy skies in Southern Brazil, Agriculture and Forest meteorology, 139(16):171-181.

4. Brunt, D., (1932). Notes on radiation in the atmosphere, quarterly Journal of the Royl Meteorological society, 58(5):389-418.

5. Wagner, Wand Prub, A., (2002). The IAPWS formulation 1995 for The thermodynamic properties of ordinary water substance for general and Scientific use, 31(2):387535.

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